LR-1479

DAVIDSON LABORATORY

Letter Report SIT-DL-70-1479

February 1970

DERIVATION OF AN EMPIRICAL EQUATION RELATING CRITICAL HYDROPLANING SPEED, WATER FILM THICKNESS, AND NOMINAL CONTACT PATCH BEARING PRESSURE, FOR AN 8" DIAMETER POLYURETHANE MODEL TIRE

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prepared for

National Aeronautics and Space Administration
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D. L. Project 3628/480

Approved:

I. Robert Ehrlich, Manager
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NOMENCLATURE

B.P.	Nominal Tire Contact Patch Bearing Pressure in lbs/in^2
D	Tire Diameter in Inches
h	Water Film Thickness in Inches
V_{cr-d}	Hydroplaning Spin Down Speed in Miles Per Hour
w	Tire Width in Inches
W	Normal Load on Tire in Pounds

OBJECTIVE

1. To derive an empirical equation relating the critical hydroplaning speed (spin down), water film thickness, and nominal contact patch bearing pressure, utilizing previously-obtained experimental data on polyurethane model tires.

2. To determine a test program, using the above result as a guideline, which will extend our experimental results closer to the operating regime of a prototype tire.

INTRODUCTION

Studies to examine the hydroplaning of aircraft tires have shown that the various wheel parameters affecting tire-hydroplaning speeds should be explored. The Davidson Laboratory and others have conducted both experimental[1,2,3,4] and theoretical[5,6] investigations. In the Davidson Laboratory studies, the Davidson Laboratory rolling road facility and scale model techniques were used to isolate the more fundamental effects related to hydroplaning inception speed.

This report describes an attempt to correlate the hydroplaning inception speed, contact patch bearing pressure, and water film thickness. The techniques of statistical analysis and "curve fitting" were applied to data previously reported on[4] and to some additional data since generated.

On analyzing the data, it was observed that plots of the square of the "critical hydroplaning speed" versus the nominal contact patch bearing pressure at various water film thicknesses produced a family of straight lines.[4] It has also been observed that when the empirical equation for critical hydroplaning speed,

$$V_{cr-d} = 10.35\sqrt{p}$$

where: V_{cr-d} = mph

p = inflation pressure in psi

previously determined by NASA researchers,[3] was plotted on the same graph with our data, it was seen to be bracketed by lines of constant water film thickness having approximately the same slope. This is very encouraging because we can, by choosing a suitable water film thickness, duplicate the equation with experimental data from our model wheel, figure 1.

It was also observed that when V_{cr}^{2-d} was plotted versus water film thickness (h) on log-log paper, with contact patch pressure as a parameter, a family of straight-line curves was produced, figure 2. These observations led to the conclusion that there must be an easily-derived relationship between these variables.

The analysis presented herein is based on experimental data obtained from an 8-inch diameter polyurethane model tire.

ANALYSIS AND RESULTS

The overall scheme of the analysis was the curve fitting to the original V_{cr}^2 (vs. B.P.) variable followed by a fit to the residual variation of V_{cr}^2 from the first curve.

More precisely, an average bearing pressure (B.P.) was determined for each tire at each load by dividing the normal load by the ground contact patch area. A linear, least square, fit was chosen to represent the relationship between V_{cr}^2 and B.P. due to the close visual fit as shown in figure 1. This resulted in

$$V_{cr}^2 = 74.04 + 65.9\ (\text{B.P.}) \qquad (1)$$

The fact that this equation does not go through the origin may be explained by the fact that the range of B.P. fitted was 4.71 to 11.59 lbs/in^2, which does not include values near the origin. The inability of linear fits to give good extrapolations is well known. The explained variation of this fit was 46.4% of the total variation.

Let the values of V_{cr}^2 as computed by (1) be called the "Expected V_{cr}^2." For the second curve, a log-log least square fit was chosen to represent the relationship between V_{cr}^2 and h, which was implemented by fitting a log-log curve to the ratio V_{cr}^2/expected V_{cr}^2 (at a given B.P.) vs. h/.02. This resulted in the following relationship:

$$V_{cr}^2/\text{expected } V_{cr}^2 = 1.05\ (h/.02)^{-.325} \qquad (2)$$

yielding an overall relationship between V_{cr}^2 and B.P. and h of

$$V_{cr}^2 = 1.05(h/.02)^{-.325}\ (74.04 + 65.9\ \text{B.P.}) \qquad (3)$$

or $$V_{cr}^2 = (h)^{-.325}\ (21.8 + 19.4\ \text{B.P.}).$$

This last equation explained 86.3% of the total variation.

Table I presents the actual values measured, and predicted values resulting from equations (1) and (3).

DISCUSSION

It must be emphasized that the model represented by (3) was derived from experimental data representing 8" diameter polyurethane model tires having four different widths and a smooth surface (bald). Therefore, the general applicability of the model to all sizes and types of tires remains to be tested. However, the fit, for an admittedly restricted situation, is sufficiently good that the model can be used as the basis for further study with full-scale and other model tires.

In comparison with the NASA formula ($V_{cr} = 10.35\sqrt{p}$), it should be noted that the two formulas exhibit slopes which are identical when the water film thickness is approximately 0.005" for the 8" diameter wheel.

It can be seen in figure 1 and equation (3) that the major influence of tire width on hydroplaning spin-down speed can be accounted for by its effect on the tire contact patch bearing pressure.

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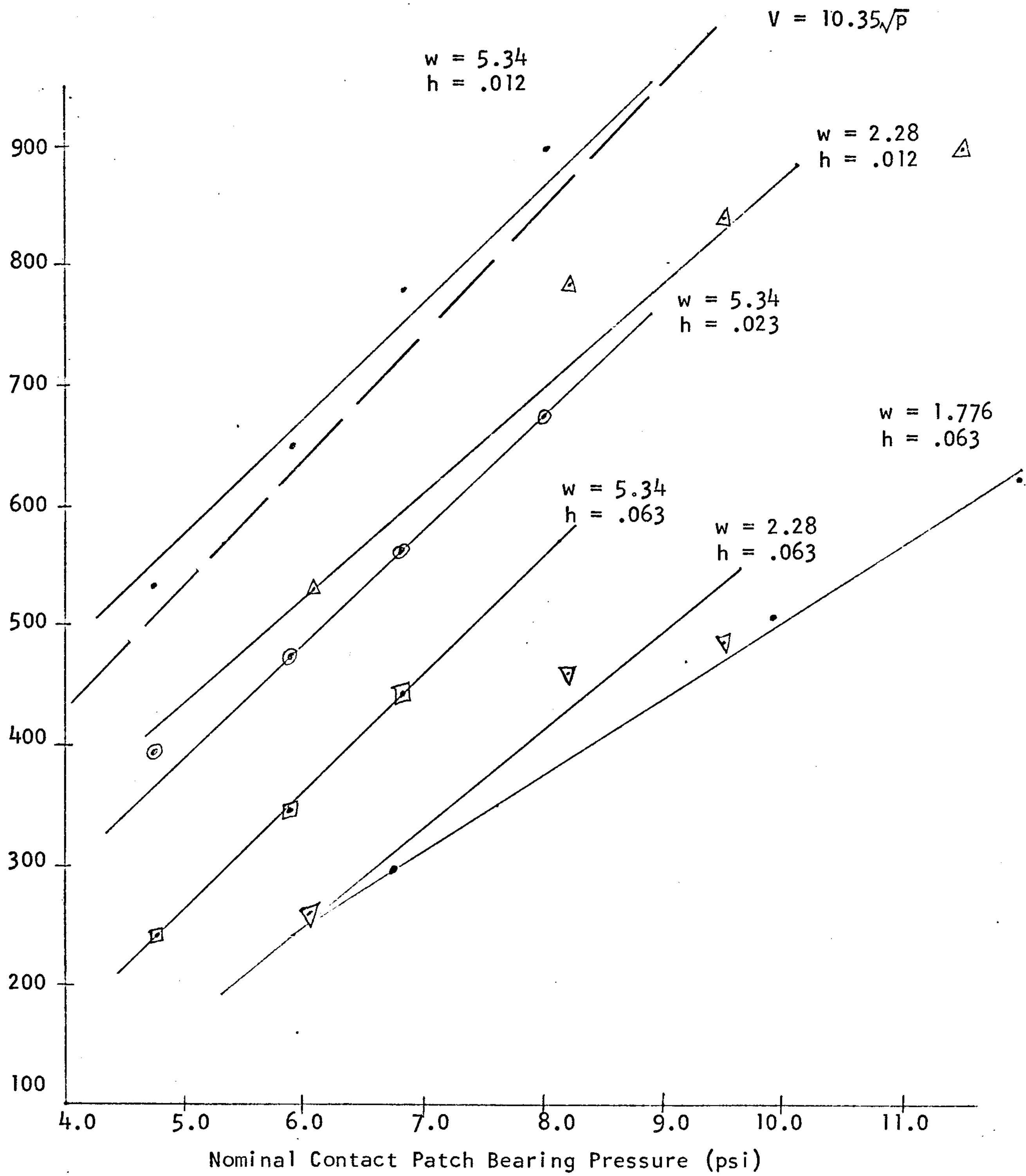
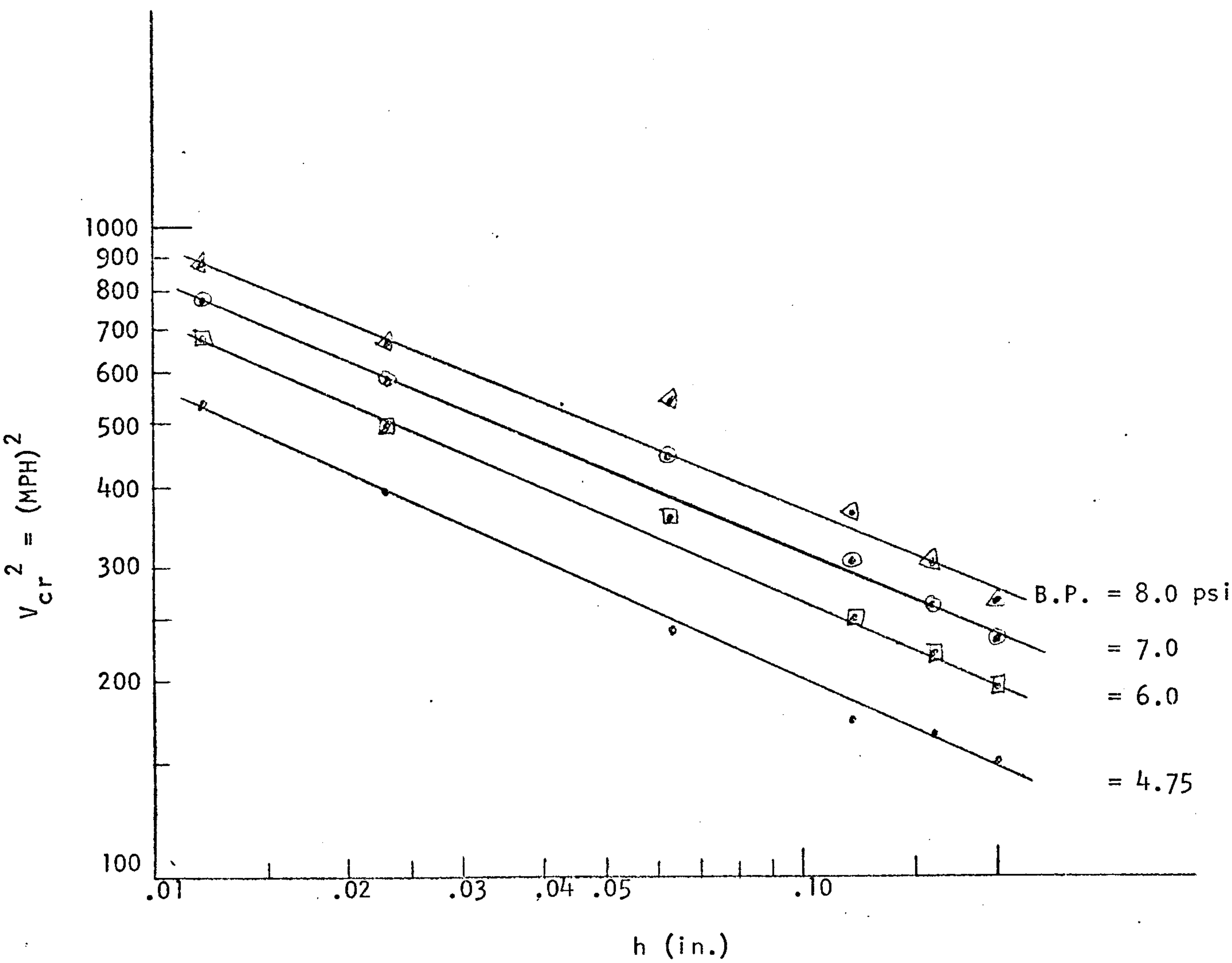


V_{cr}^2 vs. B.P. with Water Film Thickness (h) and Tire Width (w) as Parameters for an 8" Dia. Model Tire

Figure 1



V_{cr}^2 vs. Water Film Thickness (h) with B.P. as a Parameter for an 8" Dia. Model Tire with a Width of 5.35 Inches

FIGURE II

TABLE I

← Experimental Data →									
D	h	w	W	Actual V_{cr}	V_{cr}^2	B.P.	Expected V_{cr}^2 by Equation (1)	Expected V_{cr}^2 by Equation (3)	Expected V_{cr} by Equation (3)
8"	.012	5.34	17.5	23.0	529	4.71	384.47	475.97	21.8
			27.5	25.5	650.25	5.93	464.85	575.48	24.0
			38.5	28.0	784	6.78	520.86	644.83	25.4
			57.5	30.0	900	8.049	604.47	748.33	27.3
		2.28	14.0	23.0	529	6.05	472.76	585.28	24.2
			28.0	28.0	784	8.21	615.08	761.47	27.6
			42.0	29.0	841	9.53	702.05	869.14	29.5
			56.5	30.0	900	11.516	832.91	1031.14	32.1
		3.20	18.0	23.0	529	6.116	477.11	590.66	24.4
			36.5	26.0	676	7.49	567.64	702.74	26.5
			54.5	28.0	784	9.47	698.10	864.25	29.4
			54.5	30.0	900	9.47	698.10	864.25	29.4
			65.5	27.0	729	10.23	748.18	926.25	30.4
		1.78	14.0	24.0	576	6.763	519.74	643.44	25.4
			27.5	30.0	900	9.87	724.46	896.88	29.9
			41.0	31.0	961	11.95	861.51	1067.79	32.6
	.023	5.34	17.5	20.0	400	4.71	384.47	385.24	19.6
			27.5	21.75	473.06	5.93	464.85	465.78	21.6
			38.5	23.75	564.06	6.78	520.86	521.91	22.8
			57.5	26.0	676	8.049	604.47	605.68	24.6
		3.20	18.0	20.0	400	6.116	477.11	478.06	21.8
			36.5	24.5	600.25	7.49	567.64	568.78	23.8
			54.5	26.0	676	9.47	698.10	699.50	26.4
			65.5	26.0	676	10.23	748.18	749.68	27.3

TABLE I

D	h	w	W	Actual V_{cr}	V_{cr}^2	B.P.	Expected V_{cr}^2 by Equation (1)	Expected V_{cr}^2 by Equation (3)	Expected V_{cr} by Equation (3)
← Experimental Data						→			
8"	.023	1.78	14.0	23.0	529	6.763	519.74	520.78	22.9
			27.5	29.0	841	9.87	724.46	725.91	26.9
			41.0	29.0	841	11.95	861.51	863.23	29.4
	.063	5.34	17.5	15.5	240.25	4.71	384.47	291.04	17.1
			27.5	18.5	342.25	5.93	464.85	351.89	18.7
			38.5	21.0	441	6.78	520.86	394.29	17.1
		2.28	14.0	16.0	256	6.05	472.76	357.88	18.9
			28.0	21.5	462.25	8.21	615.08	465.62	21.6
			42.0	22.0	484	9.53	702.05	531.45	23.1
		3.20	18.0	16.0	256	6.116	477.11	361.17	19.0
			36.5	20.5	420.25	7.49	567.64	429.70	20.7
			54.5	22.0	484	9.47	698.10	528.46	22.9
		1.78	14.0	17.5	306.25	6.763	519.74	393.44	19.8
			27.5	22.5	506.25	9.87	724.46	548.42	23.4
			41.0	25.0	625	11.95	861.51	652.16	25.6